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THE INFLUENCE OF CHANGED EXTERNAL
CONDITIONS ON THE DEVELOPMENT
OF TWO SPECIES OF MOTHS

PROFESSOR THOMAS H. MONTGOMERY, JR.

UNIVERSITY OF PENNSYLVANIA

THESE experiments were carried out in the fall and winter of 1908-09, and their results are not without interest even though no marked changes in the insects were effected.

I. *Attacus cecropia* LINN.

Cocoons of this large Saturniid were collected in New Jersey in December and January. The controls, kept in their cocoons, were hung out-of-doors exposed to rain and sun until the latter part of April, then placed in a hatching cage in a room at out-of-doors temperature, when they hatched in May. The pupæ to be experimented upon were removed from the cocoons and kept in horizontal positions unless otherwise specified.

A. *Experiments with Light*

Direct Sunlight.—Four pupæ, lot no. 86, of which only one was healthy in appearance, were placed in direct sunlight in a warm room (21° C.) on February 5; one of them hatched on February 10 and laid eggs, while the other died. Evidently direct sunlight is not fatal to them.

Direct Sunlight behind a Heat Filter.—Twenty pupæ, lot no. 83, were laid horizontally on their dorsal surfaces with heads directed towards the sunlight, behind a vertical flat glass jar containing a saturated aqueous solution of alum, in a warm room (21° C.). They were thus placed on January 22, and all hatched in March following.

Diffuse Sunlight.—Five pupæ, lot no. 65, were placed, each vertical with head up in a test-tube in a room that never sank quite as low as freezing; all hatched between May 15 and June 2.

Five pupæ, lot no. 66, were kept under similar conditions, but placed with their heads down in the test-tubes; four of these hatched in May, the fifth being infected by parasites. Three pupæ, lot no. 69, were placed vertically in separate tubes within a moist chamber near a steam radiator in my private laboratory; two hatched in February, the third died.

B. *Experiments with the Tracheal Stigmata Covered*

Twenty pupæ, lot no. 85, were placed in a warm room (21° C.) in diffuse sunlight. On January 22 the stigmata, of which there are eight easily recognizable pairs counting those of the head, were covered with a gum-arabic solution, but this peeled off and was replaced the next day by pure Canada balsam. It is, however, quite doubtful how efficient the balsam was in excluding air from the respiratory tubules, for it does not adhere very well to the greasy surface of the cuticula. Four of these pupæ, lot 85A, had seven stigmata of the right side covered, and all hatched. Four others, lot 85B, had the first pair of stigmata covered, and all hatched. Four others, lot 85C, had the second and third pairs of stigmata covered, and all hatched. Four others, lot 85D, had the sixth and seventh pairs covered, and three hatched. Four others, lot 85E, had the fourth pair covered, and three hatched.

C. *Experiments with Higher Temperatures*

Ten pupæ, lot no. 68, were placed within a closed and dry glass jar in diffuse light, kept thus at 28° C. for 23 days, then removed from the jar and kept in diffuse light in a room at 21° C. All hatched, except three that were parasitized.

Twenty-two pupæ, lot no. 80, were placed on January

5 in an egg incubator at 39° C., kept there for varying periods, then removed into a warm room (diffuse light, 21° C.) until hatching. These were divided into lots as follows:

- 80A, 4 pupæ, incubator 1 day, all hatched in March.
- 80B, 3 pupæ, incubator 2 days, all hatched in February and March.
- 80C, 3 pupæ, incubator 3 days, 2 hatched in March.
- 80D, 3 pupæ, incubator 4 days, all hatched in March.
- 80E, 3 pupæ, incubator 6 days, 2 hatched in February.
- 80F, 3 pupæ, incubator 7 days, all hatched in February and March.
- 80G, 3 pupæ, incubator 28 days, all hatched in March.

Twelve pupæ, lot no. 84, were placed in an egg incubator from January 22 to February 18, then removed to diffuse light in a warm room (21° C.) for hatching; the temperature in the incubator was 39° C. until January 28, after that 39.5° C. Nine of these hatched in March and April.

D. Experiments with Lower Temperature

Seven pupæ, no. 41, were placed in a tight covered and dry glass jar in an ordinary ice refrigerator from December 7 to March 29, afterwards removed to a warm room; three hatched May 17, the others were destroyed by an accident.

Thirteen pupæ, no. 67, were treated similarly; two hatched on May 17, the others were killed accidentally.

E. Results of the Experiments

The pupæ were exposed to unusual external conditions: removed from the cocoon, exposed to direct sunlight with and without a heat filter, to diffuse light, to various temperatures ranging from 0° C. to 39° C., with the stigmata covered with balsam, in horizontal and vertical positions. Yet nearly as great a proportion hatched as in the case of the controls. Higher temperatures hastened the rate of development. Further, the pupæ so abnormally treated did not differ in coloration from the controls or to no extent that could be measured;

this result applies to the pattern as well as to the intensity of the coloration. For in the controls quite as great a range of color variation was found as in the others. Also the unusual conditions of life did not appear to effect the dimensions of the hatched moths. To decide this I took as the most convenient measurement the length of the fore wing, measured from its point of insertion against the thorax to the most anterior edge of a dark spot placed anteriorly near the apex of the wing; I did not measure to the extreme free edge of this wing, for that portion is very flexible and liable to become folded during the process of mounting the moths. The right wing was measured unless it happened to be misshapen. Only about a hundred moths were preserved, too few for any statistical study of this wing length, consequently in the following table only the extremes of variation of this length are given (expressed in millimeters, and accurate to within a half millimeter).

Lot 40 (1♂, 5♀) control	♂ length 67.5	♀ length 69.0-74.5
Lot 64 (2♂, 6♀) control	♂ length 61.0-65.0	♀ length 61.0-75.5
Lot 68 (4♂, 3♀)	♂ length 58.0-64.0	♀ length 64.0-73.0
Lot 69 (2♂)	♂ length 66.0-67.0	
Lot 79 (3♂, 3♀) control	♂ length 59.5-65.0	♀ length 69.0-75.0
Lot 80 (7♂, 7♀)	♂ length 61.5-70.0	♀ length 61.0-73.0
Lot 82 (3♂, 6♀) control	♂ length 67.0-69.0	♀ length 66.5-74.0
Lot 83 (12♂, 6♀)	♂ length 60.0-68.5	♀ length 67.0-73.0
Lot 84 (2♂, 4♀)	♂ length 67.0-67.5	♀ length 68.0-71.5
Lot 85 (12♂, 3♀)	♂ length 63.0-69.0	♀ length 65.5-73.0

It is probable that this late pupal stage is so advanced in its development that it can not become much modified by external changes.

II. *Thyridopteryx ephemeraeformis* STEPH.

This psychid is the common "bag-worm" or "basket-worm." The larva immediately on hatching constructs a bag or cocoon of silk covered with portions of leaves or chips, and increases the size of the bag as it grows and carries it about. At the end of the summer each attaches its bag firmly to the twig of a tree, and the male

emerges as a winged insect; probably the male does not overwinter. But the female neither forsakes her bag nor acquires wings, she is impregnated by the male within her bag. Each female produces a large number of small eggs but does not oviposit, for she dies within her bag and her dead body becomes a case for the eggs; at her death her viscera change into a soft cottony mass that acts as a further protection for the eggs. Among some 200 cocoons collected on November 24 I found about half a dozen in which the egg case, the degenerate female, was still living. This species is then a very favorable insect for obtaining eggs and early embryos in large abundance during the colder season of the year, and should prove a valuable object for experimentation.¹

The controls were kept within their cocoons out-of-doors, and hatched in the end of May. In the experiments sometimes the eggs (in early embryonic stages) were removed from the egg cases, sometimes kept in them.

A. *Experiments with Sunlight*

Direct Sunlight.—Lot no. 77, collected January 4, consisted of egg cases placed in closed dry bottles in the south window of a warm room (21° C.). 77C, kept three weeks in this sunlight, did not hatch; 77A, an untimed period in sunlight, hatched. Lot 78, collected January 4, consisted of freed eggs in corked vials without moisture, with similar exposure to the light; they were divided into four lots, placed in the sunlight for 3, 7, 10 and 14 days respectively, and all hatched about March 1.

Direct Sunlight behind an Alum Heat Filter.—Four lots of freed eggs (nos. 51, 53, 49, 50) collected January 4 were used, placed in the sun behind a heat filter for 2, 7, 18 and 28 days, respectively, and all hatched in January.

¹ A good popular account of this species is given by McCook: "Tenants of an Old Farm," New York, 1885, and this is illustrated with excellent figures. But he makes the common mistake of other naturalists in supposing that the female oviposits. See also Howard and Chittenden, circular No. 97, U. S. Department of Agriculture, 1908.

Diffuse Sunlight.—A considerable number of lots of egg cases and freed cocoons, collected November 4, were placed in diffuse north light in a warm room (21° C.), and all hatched in January and February.

B. Experiments with Colored Light

Freed eggs, collected November 4, were placed within vials immersed in colored solutions within larger bottles, the vial passing through the cork of the larger bottle and held by it. The solutions employed were: acid fuchsine in 50 per cent. and 70 per cent. alcohol; Berlin blue in distilled water; safranine O in 95 per cent. alcohol; orange G in 50 per cent. alcohol; eosine in 70 per cent. alcohol; methylen green in distilled water; picric acid in 50 per cent. alcohol; scarlet 12 gm. in 1,000 c.c. water, this last giving monochromatic light.²

In Sunlight behind an Alum Filter, then removed to diffuse light in a warm room (21° C.). Lots 43, 46, 47 were immersed in a scarlet solution, as follows:

- Lot 43 in sunlight 4 days, hatched January 15.
- Lot 46 in sunlight 28 days, hatched January 9.
- Lot 47 in sunlight 32 days, hatched January 11.

In Diffuse North Light.—The following experiments were made in a breeding room of which the temperature was a few degrees above that out-of-doors. Two different lots were raised in a fuchsine solution, one in safranine, one in orange G, one in eosine, one in picric acid. All hatched in May.

Others were placed in a room at 21° C. One series were immersed in a fuchsine solution for 7, 18, 28, 35 days, respectively, then removed to ordinary daylight; these hatched in the latter half of January and first half of February. Others were kept continuously immersed in the following solutions: Berlin blue, methyl green, scarlet, and these hatched in the first part of February.

² Vide Pennington, W. E., 1897, "A Chemico-physiological Study of *Spirogyra nitida*," Publ. Univ. Penna. Contr. Bot. Lab. 1.

C. Experiments with High Temperatures

Freed eggs, from cocoons collected November 4, were placed in an egg incubator at 39° C. for varying periods, then removed to the dark of an ordinarily warmed room (21° C.). Those kept in the incubator for periods of 1, 2, 3, 4, 5, 7 days hatched in February; those kept in the incubator for eight and eleven days did not hatch.

Ten unopened cocoons and ten egg cases placed in a dry covered slide box, and ten egg cases placed in a dry closed jar, all at 32° C., did not hatch. Five egg cases placed in a moist chamber at 28° C. hatched December 15 (these had been collected November 24). Four other egg cases, treated like the last but with less moisture, hatched in January.

D. Experiments with Low Temperatures

Six egg cases were placed out-of-doors in a closed tin box, protected from the rain. They hatched, as was to be anticipated, at the same time as the controls.

Fourteen egg cases were placed in a closed jar within an ordinary refrigerator from November 24 until March 29, then removed to a warm room (21° C.); these also hatched at the same time as the controls.

E. Results of the Experiments

I tried to raise the small hatched larvæ by placing them upon arbor vitæ within a moist chamber; but owing to the great time consumed in transferring them to fresh pieces of the food plant, I was obliged to relinquish the attempt, and they all died. Consequently I did not determine whether those hatched under the abnormal conditions differ from control larvæ of the same age.

The eggs of this species develop into larvæ under direct sunlight with and without a heat filter, in diffuse light, in all the colored lights employed, at a temperature of 39° C. provided it be not continued longer than seven days, as well as at temperatures at and slightly below freezing. But what seems to be a necessary con-

dition for development is a certain amount of moisture, for the insects die when subjected to higher temperatures within dry vessels. The main effect of increase of temperature seems to be to hasten the rate of development. Probably it is the relative thickness of the chorion of the eggs that proves their chief protection under changed external conditions.

The experiments on this moth and on *Attacus* would show that the cocoon can have no particular value by excluding the sunlight, for we have found that sunlight is not injurious to the eggs and pupæ. Probably the main value of an insect cocoon is that of protecting against enemies, though it may also be of service in preserving a proper amount of moisture; for cocoons soak up the rain and melting snow, and would retain it for a considerable while.